Attention Deficit/Hyperactivity Disorder and Reading Disorder and Reading Disorder More Alike than Different:

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Chapter 2

RD, ADHD and their comorbidity from a dual route perspective

Abstract

Background: In order to achieve further insight into the comorbidity of reading disorder (RD) and attention deficit/hyperactivity disorder (ADHD), lexical processing and rapid naming were studied in RD and ADHD. The Dual Route Cascaded model postulates that lexical processing contains two parallel processes: lexical route processing and sublexical route processing. **Method:** An orthographic decision task and a phonological decision task were used to measure lexical and sublexical route processing, respectively. In addition, a rapid naming task was used to compare 27 children with RD, 18 children with ADHD, 20 children with ADHD+RD, and 29 controls. **Results:** RD and ADHD shared impairments in accuracy of orthographic and phonological decision making as well as in rapid naming. **Conclusions:** These findings suggest that RD and ADHD may be overlapping disorders that share deficits in both lexical route and sublexical route processing. RD was dissociated from ADHD by being slower in both orthographical and phonological decision making which indicates unique deficits in RD on lexical and sublexical speed. **Keywords**: RD, ADHD, lexical processing, rapid naming, comorbidity.

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INTRODUCTION

Reading disorder (RD) and attention deficit/hyperactivity disorder (ADHD) are two common childhood disorders that frequently co-occur with estimates varying between 20-40% (Del'Homme, Kim, Loo, Yang & Smalley, 2007; Semrud-Clikeman et al., 1992). Previous studies targeting the origins of the comorbidity of RD and ADHD, focussed on phonological processing and executive functioning with mixed results (Pennington, Groisser & Welsh, 1993; Rucklidge & Tannock, 2002; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005). The current study explored other mechanisms postulated to underlie RD: lexical processing and rapid naming. These processes are considered uniquely impaired in RD, although there is evidence to suggest that lexical processing and rapid naming may also be deficient in ADHD (Semrud-Clikeman, Guy, Griffin & Hynd, 2000; Willcutt et al., 2005). By studying overlapping deficits, it may be possible to gain insight into the factors contributing to the co-occurrence of both disorders (Willcutt et al., 2005), and by investigating the non-overlapping deficits, it may be possible to determine why some children develop one, but not the other disorder (Pennington et al., 1993).

Lexical processing is the first focus of this study in order to clarify the origins of the comorbidity of RD and ADHD. The Dual Route Cascaded model has been a useful framework to understand lexical processing in RD (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). Briefly, the Dual Route Cascaded model postulates two parallel routes: the lexical route and the sublexical route. In the lexical route, a word that is read, is matched to whole word representations in the mental orthographic lexicon which contributes to efficient and fast reading. The sublexical route uses rules of grapheme-to-phoneme conversion, thus words will be read letter by letter. Both routes give access to the phonological lexicon.

In languages with a regular orthography, such as Dutch, German, Greek, and Italian, grapheme-to-phoneme relations are highly consistent, thus beginning readers master phonological processing skills after a few months of reading education (Caravolas, 2006). Learning to read in these languages relies therefore more on speed than on phonological processing skills (Georgiou, Parrila & Papadopoulos, 2008). Indeed, in regular orthographies children with RD have extremely slow but accurate reading (e.g., Italian: Brizzolara et al., 2006; Dutch: De Jong & Van der Leij, 2003; German: Wimmer, 1993). Furthermore, in German RD has been closely associated with speed impairments as assessed with rapid naming (Wimmer, Mayringer & Landerl, 1998). Thus, when phonological demands are reduced due to orthographical consistency, the influence of phonological skills on reading is limited but naming speed as an underlying cognitive deficit seems to play a decisive role for reading development. Bergmann and Wimmer (2008) argued that the slow but accurate reading of reading disordered children in consistent orthographies is due to impaired dual route processing. They hypothesise that children with RD rely predominantly on the sublexical route and are impaired in progressing from laborious serial grapheme-phoneme coding to efficient parallel coding in the lexical route. They demonstrated inaccurate lexical route processing on an orthographical decision task in German children with RD (Bergmann & Wimmer, 2008). Compared to controls, children with RD had difficulty distinguishing words (stored in the mental orthographic lexicon) from pseudohomophones (words that sound as valid words but are incorrectly spelled and therefore not stored in the mental orthographic lexicon). In contrast, the children with RD showed accurate sublexical route processing, since they had few errors but slow speed in the phonological distinction of pseudohomophones and non-words which have to be decoded letter by letter (Bergmann & Wimmer, 2008). Thus, findings of Bergmann and Wimmer indicated inaccurate lexical route processing but intact sublexical route processing in children with RD in consistent orthographies.

Slow speed and impaired lexical route processing in children with RD in consistent orthographies may suggest that lexical route processing and rapid naming tap the same processes (Hawelka, Gagl & Wimmer, 2010). Hawelka et al. (2010) hypothesised that orthographical whole word recognition of letter strings in the lexical route share similar cognitive processes as used during rapid naming of letters, numbers, colours or objects. During both orthographical whole word recognition and rapid naming, a stored representation must be recognised (e.g. a word during orthographical recognition or a letter, colour during rapid naming) and coupled to phonological word representations to pronounce the whole word or stimulus of the rapid naming task, respectively. Some studies confirmed this idea, since rapid naming correlated more strongly with orthographical knowledge and less with phonological processing skills (Georgiou, Parrila, Kirby & Stephenson, 2008) whereas others did not find a relation between orthographical skills and rapid naming (Moll, Fussenegger, Willburger & Landerl, 2009). Although results are contradictory, it is suggested that lexical route processing and rapid naming share cognitive processes.

Previous findings may suggest that deficits in rapid naming and lexical route processing may be unique to RD. Although far less studied in ADHD, studies show that rapid naming deficits and lexical route deficits are also observed in ADHD and thus are not limited to RD (Li, Shu, McBride-Chang, Liu & Xue, 2009; Kibby, Krebbs, Hill & Hynd, 2009; Raberger & Wimmer, 2003; Shanahan et al., 2006; Van de Voorde, Roeyers, Verté & Wiersema, 2010; Willcutt et al., 2010). Deficits in rapid naming and lexical route processing seem therefore important potential mechanisms to explain the overlap of RD and ADHD.

Although lexical processing in ADHD has not often been the object of research, there is evidence of lexical route deficits in ADHD (Willcutt et al., 2005). Willcutt et al. (2005) compared an ADHD group with an ADHD+RD group, RD group and a control group on an orthographical decision task. Children with ADHD were reported to be impaired in orthographic processing compared to controls, although they were less impaired than children with RD (Willcutt et al., 2005). Children with ADHD have not been found to differ from controls on sublexical route processing, since no deficits in phonological processing were observed in ADHD (Pennington et al., 1993; Willcutt et al., 2005). These findings suggest that both RD and ADHD may have impairments in lexical route processing, whereas sublexical route processing is slow but accurate in RD, at least in languages with a regular orthography.

The current study aimed to clarify the overlap and specificity of impairments in lexical and sublexical route processing and rapid naming in Dutch children with RD and children with ADHD compared to controls. Since rapid naming deficits may share the same processes as lexical route processing (Hawelka et al., 2010), we studied whether ADHD and RD in a consistent orthography, are characterised by overlapping impairments in both lexical route processing and rapid naming. Slow but accurate sublexical route processing was expected to be limited to RD. Lexical and sublexical route processing have not been studied previously in both ADHD and RD as potential mechanisms for explaining the origins of the comorbidity of ADHD and RD.

The children included were between 10-13 years of age, since at these ages reading is considered as fairly advanced and both lexical and sublexical route processing, as well as rapid naming are considered developed. We hypothesised that children with ADHD and children with RD have overlapping deficits in accuracy of lexical route processing and rapid naming, whereas only children with RD were predicted to be slower on sublexical route processing compared to controls. Children with RD and children with ADHD were not expected to differ from controls on speed of lexical route processing or accuracy of sublexical route processing.

A comorbid ADHD+RD group was included to test whether ADHD+RD is a distinct clinical condition from the single diagnosis of RD and ADHD. The comorbid ADHD+RD group has been associated with a distinct profile on rapid naming but not on lexical processing, compared to both children with ADHD only and RD only (Bental & Tirosh, 2007; Rucklidge & Tannock, 2002; Shanahan et al., 2006). Two studies showed more severe deficits in rapid naming in the comorbid condition (Bental & Tirosh, 2007; Rucklidge & Tannock, 2002), whereas one study observed less impaired rapid naming in children with comorbid ADHD+RD than in the single diagnosis groups (Shanahan et al., 2006). We expected a distinct profile on rapid naming for the comorbid ADHD+RD group. Since rapid naming and lexical route processing may share the same cognitive processes (Hawelka et al., 2010), we expected also a distinct profile on lexical route processing for the comorbid ADHD+RD group compared to the single diagnosis groups.

METHOD

Recruitment of participants

Children with RD and controls were recruited from regular primary schools. Children with ADHD and children with ADHD+RD were recruited from child outpatient clinics, special education services and an institute for remediation of RD.

RD assessment

All children were screened for the presence of RD with the Three Minutes Test (TMT; Verhoeven, 1995). The TMT consists of three cards of increasing difficulty with each card containing 150 words printed in five columns. The first two cards are used for children in the lower four classes of elementary education. In this study only the third card was used because the first two cards were deemed to be too easy for children between 10-13 years who are in the two last years of elementary education. Children were asked to read as many words as possible in one minute. The total number of words correctly read was converted into a reading grade equivalent (RGE; Struiksma, Van der Leij & Vieijra, 2004) which reflects the child's actual reading level expressed in the number of months of reading instruction (one year of instruction being equivalent to 10 months) (Van der Schoot, Licht, Horsley & Sergeant, 2000). The extent of reading retardation was computed by subtracting the RGE from the expected grade equivalent (EGE) expressed as the number of months that the child had received formal reading instruction. For the TMT adequate psychometric properties have been reported (Verhoeven, 1995).

ADHD assessment

In order to screen for ADHD symptomatology both at school and at home, teachers and parents of participating children were required to complete the Disruptive Behaviour Disorder rating scale (DBD; Oosterlaan, Scheres, Antrop, Roeyers, & Sergeant, 2001). The DBD contains 42 items and comprises four subscales composed of the Diagnostic Statistical Manual, fourth edition (DSM-IV) items for inattention, hyperactivity/impulsivity, oppositional defiant disorder (ODD) and conduct disorder (CD). The items were scored on a four-point scale (not at all, just a little, pretty much, and very much). Higher scores indicate greater symptom severity. Adequate psychometric properties have been reported (Oosterlaan et al., 2001).

Children meeting criteria for inclusion in the ADHD or ADHD+RD groups on the basis of the parent and teacher DBD (see under Selection of Groups), were administered the Diagnostic Interview for Children (PDISC-IV; National Institute of Mental Health (NIMH), Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000; Dutch translation; Ferdinand, Van der Ende, & Mesman, 1998) to confirm a diagnosis of ADHD and to establish associated disruptive disorders. The PDISC-IV is a structured diagnostic interview based on DSM-IV and on the International Classification of Diseases, tenth edition (ICD-10). Adequate reliability and validity have been reported for precursors of the PDISC-IV (Schwab-Stone et al., 1996).

IQ assessment

To estimate intelligence, four subtests of the Wechsler Intelligence Scale for Children, third version (WISC-III, Wechsler, 1992; Kort et al., 2002) were used: Picture Arrangement, Arithmetic, Block Design and Vocabulary. These four subtests correlate between r =.93 to r =.95 with Full Scale IQ (Groth-Marnat, 1997).

Selection of groups

Children in the RD and ADHD+RD were considered reading disordered when they experienced a delay of more than 15 months of reading instruction on the TMT (see Van der Schoot, Licht, Horsley & Sergeant, 2000). Controls and children with ADHD were required to have a maximum reading delay of 15 months on the TMT.

To meet the criteria for an ADHD diagnosis, both parent and teacher ratings on the DBD fell at or above the 90^{th} percentile on either the Inattention or Hyperactivity/Impulsivity subscale or both. In addition, children were required to meet an ADHD diagnosis of either subtype based on the DSM-IV on the PDISC. Controls and children in the RD group were required to obtain scores below the 90^{th} percentile on all subscales of the DBD. Children were entered in the ADHD+RD group when they met criteria for both RD and ADHD.

The final sample consisted of 94 participants including 27 children with RD (14 boys), 18 children with ADHD (15 boys), 20 children with comorbid ADHD+RD (16 boys) and 29 controls (11 boys).

The 18 children in the ADHD group were all diagnosed with ADHD combined subtype. In the ADHD+RD group, 9 children met criteria for ADHD combined subtype, 9 for ADHD inattentive subtype and 2 for ADHD-hyperactive/impulsive subtype. A comorbid diagnosis of ODD or CD according to the PDISC or already clinically established, was not an exclusion criterion. In the ADHD group, 8 children had a comorbid diagnosis of ODD and in the ADHD+RD group also 8 children had a comorbid diagnosis of ODD. One child in the ADHD+RD group met the criteria for CD.

Twenty three children in the ADHD groups were treated with stimulant medication and discontinued use at least 24 hours prior to testing. Children with neurological disorders such as epilepsy, were excluded from the study. All children were required to have an IQ of at least 75.

Final participants characteristics are shown in Table 2.1. All included children were aged between 10 and 13 years (mean age=11.1 years, SD=.83). Groups did not differ in age. Children with ADHD+RD had a lower IQ than children with ADHD and control children. Findings on the DBD and the PDISC confirmed the expected clinical group characteristics for ADHD of the ADHD and ADHD+RD groups and indicated that the two ADHD groups did not differ in the severity of ADHD symptoms.

Since the children with RD were recruited at primary schools and the children in the ADHD+RD group were recruited at a centre for reading remediation, the RD group might have been less impaired in reading than the ADHD+RD group. However, the two reading groups did not differ in severity of reading impairments as indicated by the TMT, see Table 2.1. The RD group showed an average delay of 26 months of reading instruction, whereas the ADHD+RD group had a mean delay of 33 months of reading instruction. These figures underline the severe reading impairment in the two reading disordered groups.

Table 2.1. Mean, standard deviations and pairwise group comparisons for IQ, age and ADHD and RD selection measures for the RD, ADHD, ADHD+RD and control groups.

	RD n=27 (♂=14)		ADHD n=18 (♂=15)		ADHD+RD n=20 (♂=16)		NC n=29 (♂=11)		Pairwise Group Comparisons using Tukey*
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	
IQ	101.26	13.90	104.22	12.67	91.88	10.09	106.34	10.78	A+R<A,NC
Age	11.04	.80	10.89	1.07	11.30	.78	10.97	.73	ns
DBD Parents									
Inattention	3.64	2.54	16.67	3.83	16.70	3.94	2.38	3.11	A+R,A>R,NC
H/I	1.80	2.12	16.83	4.73	13.85	8.06	1.41	1.59	A+R,A>R,NC
DBD Teacher									
Inattention	1.93	2.31	15.94	5.33	14.30	5.55	1.54	2.31	A+R,A>R,NC
H/I	.63	1.36	16.22	4.79	12.10	6.92	.46	1.03	A+R,A>R,NC
PDISC-IV									
Inattention	-	-	15.50	1.04	15.22	2.90	-	-	ns
H/I	-	-	14.66	2.94	10.22	5.71	-	-	ns
Reading[1]									
TMT card	26.89	9.14	5.11	6.43	33.10	11.25	1.52	7.45	A+R,R>A,NC

Note. A=Attention Deficit Hyperactivity Disorder, ADHD=Attention Deficit Hyperactivity Disorder, DBD=Disruptive Behaviour Disorder rating scale, IQ=Intelligence Quotient, H/I=Hyperactivity/Impulsivity, NC=normal controls, PDISC-IV=Parent Diagnostic Interview Scale for Children, R= Reading Disorder, RD=Reading Disorder, TMT=Three Minute Test.
[1]Delay in months of education.
*p<.05.

Measures

Lexical route processing. Lexical route processing was assessed using an orthographic decision task (Bergmann & Wimmer, 2008). In the orthographic decision task, participants decided whether letter strings, presented singly on a computer screen, were correctly spelled words (valid words, for example “kans” which means chance) or not (pseudohomophones, which were valid words in which one or two letters were changed and sounded like valid words when pronounced, for example “jeugt” of the valid word “jeugd” which means youth). Children were required to press the z-key on a computer keyboard for valid words and the m-key for pseudohomophones. The stimuli were monosyllabic 4 or 5 letter words with a CCVC, CVCC, CCVVC or CVVCC structure (C=Consonant, V=Vowel), see Appendix A for the items. The mean frequency of the valid words was 368.9 out of 10 million words (SD=581.8).

The mean frequency of the valid word derivations of the pseudohomophones was 377.7 (SD=451.6) (CGN; [Corpus Spoken Dutch], 2004;). The frequencies of the valid words and pseudohomophones did not differ.

The orthographic decision task commenced with a practice block of 25 letter strings (both valid words and pseudohomophones, see Appendix A), which were repeated if the child responded to 40% of the letter strings or more incorrectly. The practice block was followed by 2 blocks of 50 letter strings. Each block contained 25 valid words and 25 pseudohomophones, shown in fixed random order. Each trial started with a fixation cross illuminated for 1000 ms. In order to counteract the tendency to react in an automatic fashion, responding was possible 300 ms after stimulus onset. The maximum trial duration was 5000 ms.

Accuracy of orthographic decision making was assessed by d’ which is a measure of the ability to distinguish signal from noise (i.e. valid words versus pseudohomophones). The d’ of orthographic decision making was calculated as follows: probit (hit rate correctly identified valid words) – probit (false positive rate correctly identified pseudohomophones) (MacMillan & Creelman, 1991). In this formula, hit rate referred to the number of correctly identified valid words divided by the total number of valid words; the false positive rate referred to the number of correctly identified pseudohomophones divided by the total number of pseudohomophones. The hit rate and the false positive rate for each child were normalized by a probit function because responses were binomial. Speed of orthographic decision was measured by mean reaction time (MRT) of the correctly identified valid words and pseudohomophones.

Sublexical route processing

Sublexical route processing was assessed with a phonological decision task (Bergmann & Wimmer, 2008; Milne, Nicholson & Corballis, 2003). The phonological decision task had the same design as the orthographic decision task, only the type of letter strings differed between the tasks. In the phonological decision task, the child had to decide whether letter strings sounded like valid words if pronounced (pseudohomophones, for example “weetun” of the valid word “weten” which means to know) or not (non-words, for example “poonun” which is pronounceable in Dutch but is meaningless). The letter strings had 6 letters with usually a CVCVC structure. Children were required to press the z-key on the keyboard for pseudohomophones and the m-key for non-words, see Appendix A for the items. The mean frequency of the valid words derivations of the pseudohomophones and non-words was 490.0 (SD=653.7) out of 1 million words (CGN; [Corpus Spoken Dutch], 2004). The mean frequency of the pseudohomophones and non-words of the phonological decision task did not differ.

Similarly, to the orthographic decision task, there was a practice block of 25 letter strings (both pseudohomophones and non-words), which could be extended once by 25 words if the child responded to 40% or more incorrectly. Thereafter, two blocks of 50 letter strings were presented. Each block contained 25 pseudohomophones and 25 non-words in fixed random order.

The accuracy measure, d', was calculated as follows: probit (hit rate correctly identified pseudohomophones) – probit (false positive rate correctly identified non-words) (MacMillan & Creelman, 1991). Speed of phonological decision was measured with MRT of the correctly identified pseudohomophones and non-words.

Rapid naming

The rapid naming task consisted of four cards (Denckla, 1973). The first card contained 50 coloured squares (yellow, blue, red, black, green), the second card 50 numbers (2, 6, 9, 4, 7), the third card 50 letters (O, A, S, T, P), and on the fourth card 50 objects (ball, fish, house, pencil, car) were presented. On all cards, stimuli were printed in random order in 5 rows of 10 stimuli each. Participants were required to name the items as quickly and as accurately as possible. The dependent variable was the time required to name the items on each card in seconds. Since there were few errors, errors were not analysed, see Table 2.2 for error percentages.

Procedure

For each child first the DBD was obtained, and when applicable the PDISC was administered to the parents at their homes. When eligible, the children were individually tested during the morning in a quiet room in their school, outpatient clinic or remediation centre, depending on where the children were recruited. The tests were administered in a single session in a fixed order. The orthographical decision task was administered first, followed by the 4 WISC-III subtests, the phonological decision test, the TMT and the rapid naming test. This study was approved by the local medical ethics committee and informed consent was obtained from the parents of all participating children.

Statistical analysis

The percentage of missing data was less than 5% for all variables. Missing data were replaced by regression analysis (Tabachnick & Fidell, 2007). Extreme outliers were replaced by the next most extreme value in the distribution plus one unit to reduce their influence in the analyses (Tabachnick & Fidell, 2007).

In all analyses, group differences were studied using ANOVA with two between subjects factors: RD (2 levels: present or absent) and ADHD (two levels: present or absent). Group differences in accuracy of lexical route and sublexical route processing were tested using two separate ANOVAs with d' orthographic decision making and d' phonological decision making

Table 2.2. Performance of the RD, ADHD, ADHD+RD and control groups on lexical processing and rapid naming.

	RD n=27 (14 boys)		ADHD N=18 (15 boys)		ADHD+RD n=20 (16 boys)		C n=29 (11 boys)	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Lexical Route Processing								
Accuracy								
d' Orthographic Decision Making	1.91	.77	2.71	.75	1.64	.87	3.20	.86
Speed								
MRT Valid Words (ms)	1666.41	380.89	1290.86	337.28	1733.05	552.15	1289.78	322.64
MRT Pseudohomophones (ms)	2134.65	526.07	1540.63	485.41	2176.63	568.09	1555.52	320.44
Sublexical Route Processing								
Accuracy								
d' Phonological Decision Making	1.88	.58	2.12	.55	1.67	.59	2.66	.59
Speed								
MRT Pseudohomophones (ms)	1800.31	300.32	1501.09	305.37	1918.36	551.41	1436.84	227.09
MRT Non Words (ms)	2526.73	390.04	1861.41	410.91	2560.49	581.14	2095.52	444.03
Rapid Naming								
Colors (s)/Mean Percentage of Errors	44.00/.11	11.44/.47	43.89/.77	9.84/1.21	45.15/.33	7.91/.76	37.66/.55	7.04/.55
Letters (s)/Mean Percentage of Errors	27.48/.90	7.55/1.65	24.94/.50	5.05/1.10	31.65/1.30	6.44/2.27	23.03/.90	3.78/.90
Numbers (s)/Mean Percentage of Errors	29.85/.44	8.80/1.01	26.67/.37	5.87/.96	31.90/.22	7.17/.84	23.69/.59	5.27/.59
Objects (s)/Mean Percentage of Errors	44.81/.20	8.43/.81	44.94/.20	11.52/.81	47.45/.68	6.82/2.01	40.14/.20	7.47/.20

Note. ADHD=Attention Deficit Hyperactivity Disorder, C=Controls, RD=Reading Disorder, MRT=Mean Reaction Time.

as dependent variables, respectively. To test whether speed in lexical route processing differed between groups, we performed an ANOVA with word type (2 levels: valid words and pseudohomophones of the orthographical decision task) as within subject factor. Group differences on speed of sublexical route processing were tested with an ANOVA with word type (two levels: pseudohomophones of the phonological decision task and non-words) as within subject factor. In order to test group differences for speed of rapid naming, we used an ANOVA with stimulus type as within subject factor (4 levels: colours, objects, letters, numbers). Since group differences were the focus of this study, main effects of within subject factors are not reported in the interest of space limitations and are available on request to the first author. Post hoc testing was performed using Tukey t-tests. All analyses were repeated using IQ as a covariate since groups differed in IQ. In addition, we studied the effect of sex on the results since sex ratios were unbalanced across the four groups.

RESULTS

Table 2.2 displays the results on the orthographic and phonological decision tasks and on the rapid naming task for the four groups.

Lexical route processing. Main effects for both RD and ADHD were found for d' orthographic decision which measures accuracy of orthographic decision making, RD: $F(1,90)=46.07$, $p<.001$, $\eta_p^2=.33$ and ADHD: $F(1,90)=4.71$, $p<.03$, $\eta_p^2=.05$. These findings indicate that both RD and ADHD are associated with poorer accuracy in lexical route processing. The RD by ADHD interaction was not significant for d' orthographic decision, $F(1,90)=.41$, $p<.52$, $\eta_p^2=.005$, demonstrating that the performance of the comorbid group reflects additive effects rather than interactive effects of ADHD and RD.

Children with RD had slower MRTs on the orthographic decision task than children without RD, indicating slower orthographic decision making speed in RD, $F(1,90)=33.79$, $p<.001$, $\eta_p^2=.27$. However, the main effect of RD was modified by word type since the RD by word type interaction for MRT on the orthographic decision task was significant, $F(1,90)=11.36$, $p<.001$, $\eta_p^2=.11$. Figure 2.1 shows that children with RD were relatively slower on pseudohomophones than valid words compared to children without RD. Post hoc testing showed that children with RD were slower than children without RD on both valid words, $t(82)=4.80$, $p<.001$ and pseudohomophones, $t(82)=6.01$, $p<.001$. Further, the ANOVA with word type as within subject factor was rerun for children with RD and children without RD separately. Both children with RD and children without RD were slower on pseudohomophones than on valid words, RD present: $F(1,46)=119.1$, $p<.001$, $\eta_p^2=.72$ and RD absent: $F(1,46)=,45.09$ $p<.001$, $\eta_p^2=.49$.

In contrast, ADHD was not associated with slower orthographic decision making speed, $F(1,90)=.02$, $p<.87$, $\eta_p^2<001$, nor was the ADHD by word type interaction significant, $F(1,90)=.11$, $p<.73$, $\eta_p^2=.001$. The RD by ADHD interaction was not significant for orthographic decision making speed, *F*(1,90)=.12, *p*<.72, η_p^2=.001, nor was the RD by ADHD by word type interaction significant, *F*(1,90)=.005, *p*<.94, η_p^2=.001.

Taken together the findings for orthographic decision making speed indicate that RD but not ADHD is associated with slow orthographic decision making speed suggesting slow lexical route processing in RD. The effects of RD on speed of lexical route processing were not influenced by the presence or absence of comorbid ADHD.

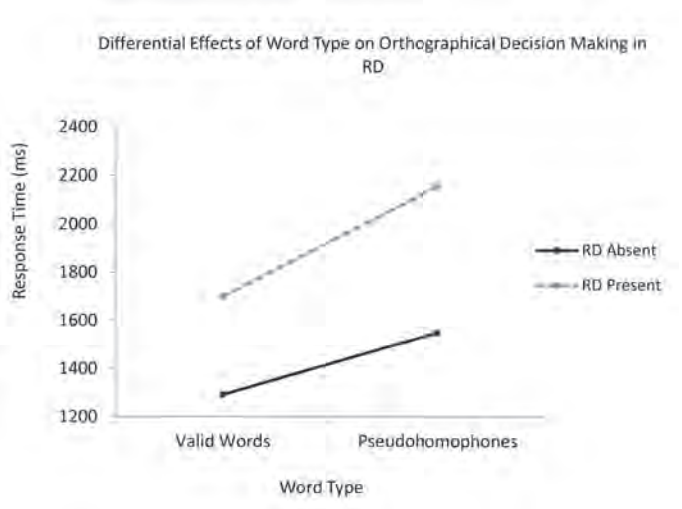

Figure 2.1. Significant interaction between RD (present versus absent) and word type (valid words versus pseudohomophones) during orthographic decision making. Children with RD appeared relatively slower on pseudohomophones compared to valid words than children without RD.

Sublexical route processing

Main effects for both RD and ADHD were found for d’ phonological decision making that measures accuracy of phonological decision making, RD: *F*(1,90)=24.80, *p*<.001, η_p^2=.21 and ADHD: *F*(1,90)=9.32, *p*<.003, η_p^2=.09. These results show that, contrary to predictions, both RD and ADHD were associated with poorer accuracy of sublexical route processing. The RD by ADHD interaction was not significant for d’ phonological decision making, *F*(1,90)=1.77, *p*<.18, η_p^2=.01, indicating that the performance of the comorbid group reflects additive effects rather than interactive effects of ADHD and RD.

Children with RD had slower MRTs on the phonological decision task than children without RD, indicating slower phonological decision making speed in RD, *F*(1,90)=36.95, *p*<.001, η_p^2=.29. The RD by word type interaction for MRT for the phonological decision task was significant, *F*(1,90)=11.36, *p*<.001, η_p^2=.11. Figure 2.2 shows that children with RD were relatively slower in processing non-words than pseudohomophones than children without RD. Post hoc comparisons indicated that children with RD were slower than children without

RD on pseudohomophones, $t(82)=5.20$, $p<.001$ and non-words, $t(82)=5.81$, $p<.001$. Further, the ANOVA with word type as within subject factor was rerun for children with RD and children without RD separately. It was found that both children with RD and children without RD were slower on non-words than on pseudohomophones, RD present: $F(1, 46)=223.38$, $p<.001$, $\eta_p^2=.83$ and RD absent: $F(1,46)=84.09$ $p<.001$, $\eta_p^2=.69$.

ADHD, in contrast, was not associated with phonological decision making speed, $F(1,90)=.02$, $p<.95$, $\eta_p^2<.001$, Unexpectedly, ADHD interacted significantly with word type for MRT for the phonological decision task, $F(1,90)=7.75$, $p<.007$, $\eta_p^2=.07$. Follow-up tests, however, could not identify significant differences between children with ADHD compared to children without ADHD on pseudohomophones and non-words, pseudomohomophones: $t(92)= 1.23$, $p>.10$ and non-words, $t(92)=1.04$, $p>.10$. These findings suggest that the ADHD by word type interaction does not pinpoint meaningful differences in phonological decision making speed for non-words and pseudohomophones in ADHD. The RD by ADHD interaction and the RD by ADHD by word type interaction were not significant for MRT for the phonological decision task, $F(1,90)=1.04$, $p<.30$, $\eta_p^2=.01$ and $F(1,90)=2.42$, $p<.12$, $\eta_p^2=.02$, respectively.

These results indicate that RD but not ADHD, is associated with slower sublexical route processing. The effects of RD on speed of sublexical route processing were not influenced by the presence or absence of comorbid ADHD.

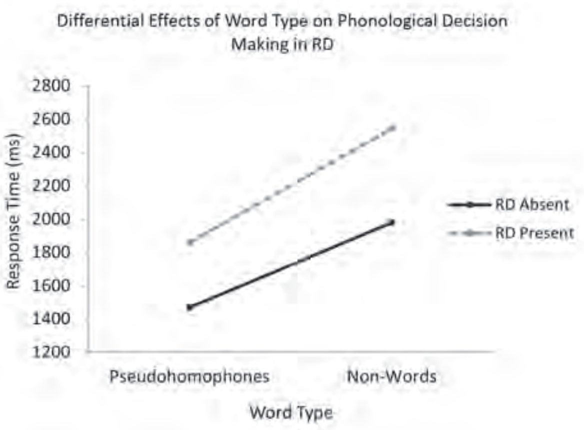

Figure 2.2. Significant interaction between RD (present versus absent) and word type (pseudohomophones versus non-words) during phonological decision making. Children with RD appeared relatively slower on non-words than on pseudohomophones compared to children without RD.

Rapid naming

Main effects for rapid naming were noted for both RD and ADHD, RD: $F(1,90)=11,35$, $p<.001$, $\eta_p^2=.11$ and ADHD: $F(1,90)=5.47$, $p<.02$, $\eta_p^2=.05$. These results suggest that slower rapid naming is implicated in both RD and ADHD. The RD by ADHD interaction was not significant, $F(1,90)=.28$, $p<.59$, $\eta_p^2=.003$, indicating that the performance of the comorbid group reflects additive rather than interactive effects of ADHD and RD.

RD and ADHD did not significantly interact with stimulus type, RD: $F(3,235)=.29$, $p<.29$, $\eta_p^2=.01$, ADHD: $F(3,235)=.32$, $p<.77$, $\eta_p^2=.004$. The RD by ADHD by stimulus type interaction was not significant, $F(3,235)= 2.27$, $p<.09$, $\eta_p^2=.02$. These results indicate that stimulus type of rapid naming did not have a differential effect on the groups.

Effects of IQ and sex

Covarying for IQ left findings unchanged with one exception: Main effects of ADHD disappeared on accuracy of orthographic decision making after covarying for IQ.

Since sex ratios were unbalanced, we tested whether sex impacted on our results. For none of the dependent variables a significant ADHD by sex, RD by sex, ADHD by RD by sex interaction effect was obtained (η_p^2 range:.002 to .02). Since sex did not interact with ADHD or RD, we concluded that our results were not influenced by sex.

DISCUSSION

This study focused on the overlap and specificity of impairments in lexical and sublexical route processing, as well as rapid naming in RD and ADHD. As expected, impairments in lexical route processing were found in both RD and ADHD since both disorders were associated with poor accuracy of orthographic decision making. However, lexical route impairments were more severe in RD: children with RD were not only less accurate compared to children without RD, but also slower on orthographic decision making and on pseudohomophones (which are orthographically more complex than valid words) in particular.

Contrary to predictions, both RD and ADHD were associated with deficient sublexical route processing since both RD and ADHD were associated with less accurate phonological decision making. Sublexical route processing impairments were more severe in RD, since RD was also associated with slower sublexical route processing. Children with RD showed the expected speed impairments on phonological decision making in general and on non-words (which place higher demands on sublexical processing than pseudohomophones) in particular.

As predicted, both RD and ADHD exhibited slower rapid naming. For all rapid naming measures, findings for RD were unaffected by the presence or absence of comorbid ADHD. Likewise, the results for ADHD were unaffected by the presence or absence of comorbid RD.

We did not expect inaccurate sublexical route processing in ADHD or RD. There are at least two possible explanations for our finding. Firstly, our unexpected finding might have been due to length of the non-words and pseudohomophones used in the phonological decision task. The so-called 'word length effect' refers to the common finding that longer words take more time to recognize than shorter words since more letters have to be decoded (De Luca, Barca, Burani & Zoccolotti, 2008; Juphard, Carbonnel & Valdois, 2004; Martens & De Jong, 2006). Since children with RD are slower in decoding letters, these children are more disadvantaged by the word length effect compared to typically developing readers (Martens & De Jong, 2006; Zoccolotti et al., 2005). Because words in the phonological decision task always consisted of six letters, we were not able to study the impact of word length in this task. However, we were able to test the word length effect in the orthographical decision task, since this task consisted of four and five letter words. We found that word length did not affect speed of orthographical decision in ADHD, RD or both ADHD and RD. However, word length affected accuracy of orthographical decision in both ADHD and RD because ADHD and RD were more associated with lower accuracy on five letter words than on four letter words. (see Appendix B for results). On the basis of this finding, it could be argued that our findings on accuracy of orthographical decision in ADHD and RD might have been confounded by the word length effect, whereas speed on orthographical decision in ADHD and RD is not likely to be influenced by the word length effect. Future studies should focus on whether inaccurate phonological decision in ADHD and RD might have been (partly) due to the word length effect.

Secondly, the unexpected finding of poorer accuracy in phonological decision in RD might be explained in terms of the slow sublexical route processing. Because of the fixed pacing of the phonological decision task, responses which exceed the response window result in omission errors. Indeed, we found that RD but not ADHD interacted with word type (two levels: pseudohomophones and non-words) for omission errors on the phonological decision task, RD by word type; $F(1, 90)=6.11$, $p<.01$, $\eta_p^2=.06$ (ADHD by word type; $F(1, 90)=.08$, $p<.77$, $\eta_p^2=.001$, ADHD by RD by word type; $F(1, 90)=.32$, $p<.57$, $\eta_p^2=.004$). This interaction was explained by higher number of omission errors on non-words than on pseudohomophones in children with RD compared to children without RD. These findings may indicate that inaccurate phonological decision in RD was a reflection of the expected longer sublexical route decoding time in RD which was further underlined by the longer decoding time of the non-words in particular.

The unexpected inaccurate sublexical processing in ADHD may be due to deficits in working memory reported in ADHD (Martinussen, Hayden, Hogg-Johnson & Tannock, 2005). Since letter strings in the phonological decision task could not be processed in an automatic fashion like the valid words in the orthographic decision task and since letter strings in the phonological decision task were longer than in the orthographical decision task (on which no speed impairments were observed in ADHD), letter strings of the phonological decision task may have required more working memory resources than the orthographical decision task. Future studies should elaborate on this issue and investigate the possibility that sublexical route deficits in ADHD are due to or associated with working memory demands.

We found that slow speed of lexical and sublexical route processing was related to having RD but not ADHD. Slow speed of lexical and sublexical route processing together with slow speed on all stimulus types of rapid naming in RD support the double deficit hypothesis model of RD (Wolf & Bowers, 1999). This model postulates that a deficit in phonological processing is the core deficit of RD. In addition, this model proposes slow rapid naming as a second independent underlying cognitive impairment in RD. Especially in languages with regular orthographies, speed deficits in reading are characteristic for individuals with RD (Van den Bos, 1998), which is underlined by our findings. Wolf and Bowers (1999) argued that impairments in speed of rapid naming might pinpoint a generalized temporal processing deficit. It is unclear, however, whether RD is characterised by general speed deficits since some studies found slower speed of processing in both RD and ADHD, although in these studies RD was more impaired than ADHD (Shanahan et al., 2006; Willcutt et al., 2005). Future studies should determine whether general speed impairments are unique to RD, or whether only speed in the *reading domain* is implicated in RD.

Our findings indicate that both RD and ADHD are associated with deficits in rapid naming, which confirms earlier findings (Tannock et al., 2000; Semrud-Clikeman et al., 2000). Neuroscientific evidence may explain the overlap in rapid naming between RD and ADHD. Following, Nicholson, Fawcett and Dean (2001), RD is due to a failure in automatisation of processing because of impairments in the cerebellum, which becomes evident in deficient rapid naming, but also in deficient balance and skilled motor behaviour. Deficits in the cerebellum occur also in ADHD (e.g. Bledsoe, Semrud-Clikeman & Pliszka, 2009; Vaidya & Stollstorff, 2008), which may explain rapid naming deficits in children with ADHD. Further studies should investigate whether rapid naming deficits in ADHD and RD may be due to common impairments in the cerebellum.

In contrast to the findings of Rucklidge and Tannock (2002) and Bental and Tirosh (2007), no evidence was found here for a distinct profile of rapid naming impairments in comorbid ADHD+RD group. No evidence was found for the *aetiological subtype* hypothesis which proposes that comorbid ADHD+RD is a different disorder than the single diagnoses ADHD and RD (Purvis & Tannock, 2000). Our results, in contrast, indicate that there were overlapping impairments in RD and ADHD on rapid naming and accuracy of lexical and sublexical processing, providing support for the *common aetiology hypothesis,* which states that common underlying aetiological factors may lead to different disorders (Willcutt et al., 2005).

The results of the current study should be interpreted in the light of some limitations. Firstly, the ADHD+RD group had a lower IQ than the ADHD and control group. Although results remained essentially unchanged after covarying for IQ, the main effect of ADHD on accuracy of orthographic decision disappeared, which suggest that impairments in lexical route processing in ADHD were at least partly dependent on IQ. Future studies should match groups on IQ to isolate possible effects of IQ. Secondly, our groups were not balanced in the distribution of both sexes. However, sex did not interact with RD or ADHD for any of the dependent variables. Thirdly, children in the RD group and the comorbid ADHD+RD group were recruited at different settings which might have caused differences in severity of reading deficits which however appeared not to be the case. Fourthly, the orthographical decision task consisted of four or five letter strings, whereas the phonological decision task consisted of six letter strings. Future studies should use an orthographical and a phonological decision task containing letter strings equal in length to rule out possible confounding effects of the word length effect. Fifthly, the two ADHD groups had different ADHD subtype rates: the ADHD group consisted only of children with ADHD combined type, whereas all three subtypes of ADHD were represented in the ADHD+RD group. However, since there was no indication that the two ADHD groups performed differently, we assume that the different ADHD subtype rates had no effects on the results. Lastly, in this study rapid naming total time was used. However, it remains unclear how rapid naming total time is related to reading since it may be a multicomponent measure. Data on inter-item pauses and on articulation time of rapid naming suggest that these two components are independent and contribute uniquely to reading (Georgiou, Parilla & Kirby, 2009). Future studies should incorporate these two components of rapid naming to clarify this issue.

In summary, RD and ADHD may be overlapping disorders with shared deficits in lexical route processing, sublexical route processing and rapid naming. RD can be dissociated from ADHD by lexical and sublexical speed. No support was obtained for ADHD+RD as a separable clinical entity, since ADHD+RD could not be distinguished from either ADHD or RD.